RF POWER DEVICE WITH ON-CHIP DIGITAL CONTROL AND OPTICAL INTERFACE

Field of the Invention

[0001] This invention relates generally to systems employing radio frequency (RF) power devices, and more particularly, systems featuring integrated RF power devices and control.

Background of the Invention

[0002] Communication systems are known comprising a plurality of base stations that provide communication services to remote or mobile units located in corresponding service coverage areas of the base stations. Remote unit receivers include circuits for measuring the signal strength of received signals and transmitting a received signal strength indication (RSSI) to a monitoring base station to indicate the signal strength of the carrier received by the receiver. To account for changes in RSSI as the remote unit moves and so forth, the serving base station will issue commands directing the remote unit to increase or decrease its power as the need arises. Typically, as the remote unit moves to the periphery of or into an obstructed location in the serving base station coverage area, the transmit power of the remote unit as well as the transmit power of the base station must be increased to account for an increase in path losses between the serving base station and the remote unit.

[0003] If insufficient RF power is produced by the base station transmitter to transmit a modulated carrier, the remote receiver cannot accurately demodulate voice signals and decode the data. On the other hand, if the base station's transmitter transmits the carrier signal with too much power, the performance of adjacent channels may be affected and possible jamming thereof may result.

[0004] RF power devices and circuits, such as those used in cellular telephone base stations, typically include power amplifiers. As well known, base stations are often exposed to a broad temperature range and varying RF power. In addition to variations in temperature and RF output power, there are also variations in bias voltage, frequency and load impedance. A need often arises to compensate for inadvertent changes of bias current in RF power amplifiers over temperature, power fluctuations, bias voltage frequency, or load impedance. In non-constant envelope applications such as code division multiple access (CDMA) or time division multiple access (TDMA), in particular, control of quiescent current is often needed to improve the response linearity or gain flatness of the power amplifiers, while for constant

envelope applications such as the global system for mobile communications (GSM) bias voltage drop compensation is often needed to control output power or efficiency.

[0005] FIG. 1 represents a conventional system **100** for monitoring RF power device performance and handling fault management in which input and output direct current (DC) detection circuitries **101**, **102**, and reverse and forward RF detection circuitries **103**, **104**, are used to sense the operation state of the RF power device **108**. They are implemented in a different chip, wafer or discrete components mounted on printed wiring board or substrate from the RF power device chip **106**. The detected information is formatted by data formatting circuitry **111** and then transmitted via hardwire means **112** to separate diagnostic and control circuitry **114** used to process, interpret, and diagnose the detected information. The hardwire means **112** is typically an electrical connection made conventionally via printed traces on a printed wiring board. Fault management and control signals are relayed back to the RF power device **108** via the same hardwire means **112** on the PC board.

[0006] However, the use and reliance on the hardwire means as the communication link for the detected information and the fault management signals has problems. For instance, the hardwire electrical connection is subject to coupling from the high power RF signal associated with the operation of the nearby RF power device. This can lead to malfunctions in the circuitries, unless appropriate bypassing components are provided in the interconnect lines and circuitry, that typically increases design complexity and manufacturing costs. The hardwire means also can cause instability due to the creation of sneak feedback paths or RF loading of the RF amplifier input and output matching circuits.

[0007] Another drawback associated with conventional RF power device fault detection systems is the necessity of using an assembly of different dies, chip set or discrete components mounted on printed wiring board or substrate, to support the detection circuitries and the RF power device. Interconnecting these various separate dies for intercommunication and operation creates design, fabrication and performance issues. The off-chip arrangement of the detection circuitry can induce mismatch errors in the RF power circuitry. Also, the hardwired multi-chip arrangements are susceptible to interconnect failures, which reduces reliability. The inter-chip hardwiring arrangement also can slow the system's performance speed.

[0008] There are also conventional circuit tester systems applied to test a circuit by making use of one or more coaxial cables or optical fibers as an optical interface that physically extend between a device-under-test and a probe card, which is in turn connected to

a load card and a circuit tester. As will be appreciated, communication links requiring physical interfaces between a device-under-test and a circuit tester can be more tolerable when the device-under-test is not yet installed in an enclosure or other location difficult to access under which it will be actually put into service.

Brief Description of the Drawings

[0009] The above needs are at least partially met through provision of the RF power device with on-chip digital control and an optical interface described in the following detailed description, particularly when studied in conjunction with the drawings, wherein:

[0010] FIG. 1 is schematic block diagram of a conventional RF power device fault detection and control system;

[0011] FIG. 2 is schematic block diagram of an RF power device fault detection and control system in accordance with an embodiment of the present invention;

[0012] FIG. 3 is schematic block diagram of an isolated portion of the RF power device fault detection and control system illustrated in FIG. 2 used in accordance with one embodiment of the present invention;

[0013] FIG. 4 is a schematic diagram of an RF detection circuit in the isolated portion of the system illustrated in FIG. 3 used in accordance with one embodiment;

[0014] FIG. 5 is a cross sectional view of a power module containing the RF power device fault detection and control system illustrated in FIG. 2;

[0015] FIG. 6 is a block diagram of a communications system including a base station including a transmitter incorporating the RF power device fault detection and control system illustrated in FIG. 2 and mobile units;

[0016] FIG. 7 is a block diagram showing a base station including a transmitter incorporating the RF power device fault detection and control system illustrated in FIG. 2; and

[0017] FIG. 8 is a schematic block diagram in elevation view of the RF power device chip constructed according to an embodiment of the present invention.

[0018] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of various embodiments of the present invention. Also, common but well-understood elements that are useful or necessary in a commercially

feasible embodiment are typically not depicted in order to facilitate a less obstructed view of these various embodiments of the present invention.

Detailed Description of the Drawings

[0019] Pursuant to these various embodiments, a radio frequency device module can comprise an active radio frequency power device having a control signal input and digital control logic that is formed integral to the active radio frequency power device. In a preferred embodiment this digital control logic will comprise an information input and a control signal output that is operably coupled to the control signal input of the active radio frequency power device. In a preferred embodiment the radio frequency device module will also comprise a free-space optical communications interface that is also formed integral to the active radio frequency power device and that has a received signal output that is operably coupled to the information input of the digital control logic.

[0020] In a preferred approach, the module will further comprise an operational status detector that is also formed integral to the active radio frequency power device and that has an input that is responsive to an operational state of the active radio frequency power device and a detected status output that is operably coupled to an input of the free-space optical communications interface. Depending upon the needs of a given application, the operational state noted above can comprise any of a direct current value that is associated with the active radio frequency power device (such as, but not limited to, a bias level), a radio frequency power condition that is associated with the active radio frequency power device (such as, but not limited to, forward and or reflected power levels), a thermal state that is associated with the active radio frequency power device, to name a few.

[0021] So configured, within a single integrated structure such as a single integral integrated circuit, an active radio frequency power device can operate and be monitored with respect to at least one operational state to provide resultant monitoring information electrical signals, which electrical signals can then be converted to corresponding resultant monitoring information optical signals in optical free-space. A variety of benefits are achieved including reduced costs and form factor requirements along with potentially increased efficacy and improved control and response.

[0022] Referring to FIG. 2, an RF Power device diagnostics and fault management system **200** is housed within an enclosure **205** in modular form. RF power device **208** is implemented in chip or wafer **206** together with operational state detection circuitry such as

DC detection and control circuitry **201**, **202**, respectively, RF detection and control circuitry **203**, **204**, respectively, and/or a thermal detector such as a temperature sensor **235** (such as a thermistor) that is positioned proximal to the RF power device **208** to thereby sense a present thermal state thereof. Such elements can be used to directly or inferentially sense various operational states or properties of the RF power device **208**. Voltage supply conductor **218** is at an operating potential of RF power device (chip or wafer) **206** relative to ground potential at voltage supply conductor **2180**. Although this illustration describes RF detectors, DC detectors, and thermal detectors as forming part of the RF power device system, it will be understood that only one may be needed to provide the desired or needed level of diagnostic functionality for a give application, and that all types of detectors may not be desired or needed in every application.

[0023] A bi-directional optical interface **210** is provided between the RF power device chip or wafer**206** bearing the RF power device **208** and the separate or external diagnostics processing and control chip or circuit **214**. This optical interface **210** is supported by an optical driver/detector **213** fabricated in RF power device chip **206**, which functions as on-chip optical signal emitter and detector, which is used together with an I/O optical window **219** formed in a wall of RF Power Device package **207** to emit (or receive) optical signals **227** (or **229**) (it will be understood that such optical signals can be any optical signals including analog signals and digital signals).

[0024] Data formatting and control circuitry **211** also is implemented in the RF power device chip **206**, which processes the electronic signals **221** and **223**, and so forth, received from the detection circuitries and reformats them into data signals **225** that are processable by the optical emitter/detector component **213**. The optical data signals are transmitted off RF power device chip **206** as optical signals **227** that are propagated through free space via the optical interface **210**. That is, the optical signals **227** sent through the optical interface **210** are sent through air or other gaseous environment or a vacuum, and not through physical communication media such as optical fibers, coaxial cables, hard wires, or so forth. A complementary, synchronized optical driver/detector **217** also is provided on separate chip or circuit **214** to detect signals **227** and transmit control or feed back signals **229** back from diagnostic processing and control circuitry on chip or circuit **214** to chip **206**. In addition to the bidirectional optical interface **210**, an optional local diagnostic optical link **230** can provide a visible local diagnostic optical signal (such as, for example, a red optical output, a green optical output, or the lack of any visual output) emitted through an optical window **219**

and that is discernable by the human eye for local diagnostic purposes such as rapid and easy identification of a faulty RF power device **208** or RF power device chip or wafer **206** so that service can proceed quickly and efficiently. (If desired, this locally discernable visual cue can alternatively be served by the outbound portion of the bi-directional optical interface **210**.)

[0025] As noted above, the RF power device package **207** can include an output "window" **219** that has good transmission properties in the optical region. An example of this is a light emitting diode (LED) for the outbound link and a photo detector for the inbound link, both coupled between the inside and outside of the package **207** enclosing the RF power device chip or wafer **206** by one or more lenses.

[0026] Package **207** contains the above components and is mounted within enclosure **205**. The optical interface **210** provides a bi-directional optical communication link between fault detection data processing circuitry implemented on the first chip **206** located inside the enclosure **205** together with off-chip diagnostic processing and control integrated circuitry **215** provided on a separate chip or circuit **214**. Diagnostic and control chip or circuit **214** can communicate with higher level control systems **216** within the same base station in which the RF Power device diagnostics, fault management and control system **200** is used. Higher level control system **216**, as such, does not form part of the RF Power device diagnostics, fault management and control system **200**, although it can interact with it as described herein.

[0027] As seen in this embodiment of the present invention, an RF power device integrates both the detector circuits and a means to transmit the detected information from the RF power device via a non-physical optical link for subsequent detection at an interface point to interpretation and processing circuitry. Further, the optical link can be bi-directional, allowing fault management signals to be sent back to the RF power device in response to the detected RF power device conditions, states, or properties. More particularly, the present invention integrates DC circuitry,RF circuitry, and thermal detector circuitry into an RF Power device along with circuit means to collect and format the data from the detectors, and modulate an optical driver that outputs an optical signal from the device for subsequent reception and processing at a nearby, off-chip location provided within the same enclosure as that housing the RF power device. This invention makes possible the use of an optical link using free space propagation between the RF power devices used in RF power amplifiers, and the circuitry used to interpret and process diagnostic information indicative of the operating

parameters of the RF power device, and if necessary, provide fault management and control feedback on the detected conditions.

[0028] Referring to FIG. 3, an isolated portion of the RF power device fault detection and control system illustrated in FIG. 2 is represented as forming part of a transmitter **300**. The purpose of this illustration is to exemplify one non-limiting mode for implementing an RF detection circuit, such as circuit **204**, in FIG. 2. The transmitter includes frequency generation circuits (not shown) and RF and baseband processing circuits (not shown) and includes the power amplifier **308** comprised of at least a first RF power device **208** (and optionally at least first DC and RF detection and control circuits and thermal detection circuits) for amplifying an RF carrier modulated with baseband signals. A single power amplifier **308** is shown merely to simplify the illustration, but it will be appreciated that a multi-stage, cascade, or parallel amplifier arrangements also can be used that are conventionally used for that purpose in RF transmitters.

[0029] The sampling of the transmitted power by the power amplifier can be efficiently done by use a directional coupler or voltage rectifier according to techniques that are generally known in the RF power device field. The directional coupler or voltage rectifier is formed in the RF Power device chip **206** previously discussed by applying semiconductor processing methods and materials referenced herein. In general, when using a directional coupler, the forward transmitted power is sampled and provided as an output at a "forward" port of the coupler. In the event reflected power is of interest, the reflected power of a transmitter is sampled and provided as an output at a "reverse" port of the directional coupler. In general, the sampled power at the forward port of the coupler is converted to a DC voltage and may be used in a feedback loop involving the above-mentioned diagnostic chip **214** to increase or decrease the transmitter power or RF power device input power to maintain the same at a specified level or adjusted to some other appropriate level.

[0030] In the non-limiting illustration as shown in FIG. 3, the amplified RF carrier, as modulated by other signals, is coupled through the directional coupler to a duplexer **313**, which then couples the amplified signal to the antenna **315** for radiation thereof. The directional coupler is of conventional semiconductor design. The amplified signal can be coupled therethrough to either an optional duplexer **313** substantially unattenuated, or alternatively the transmitter may be coupled directly to an antenna in one-way systems, such as one-way paging, or in systems that employ antenna diversity. A forward sampling port (not shown) of the directional coupler **310** may couple a portion of the RF energy to an RF

detector circuit **311**. The RF detector circuit rectifies the RF signal and converts the same to a corresponding DC signal. The DC signal output by the RF detector circuit **311** is representative of the transmitter power output by the power amplifier **308**. Power circuit diagnostic and control circuitry **215** is included on chip **214**, which receives the sensed information by the RF detector circuit via the above-mentioned data formatting and control circuit **211**, optical driver/detector **213**, and optical interface **210**. The power control circuitry **215** at chip **214** compares the data based on the DC signal output by the RF detector circuit **311** and provides an error signal to the power amplifier **308**. The error signal is of such a magnitude and polarity so as to change or modify the power output by the power amplifier **308** and maintain the same at a predefined level or adjust to another value if appropriate. Should the prescribed transmitter power be intentionally changed to a new level, the reference level of the power circuit control circuit is changed accordingly, whereupon the power amplifier **308** is caused to produce a new transmitter power output.

[0031] Referring to FIG. 4, the RF detector circuit **311** implemented in semiconductor chip **206** including an RF rectifier diode **401** for providing rectification of the sampled power signals existing at the sample port of the directional coupler **310**. Diode rectifiers are routinely incorporated into RF detector circuits. At constant RF power carrier by the main line (not shown) of the directional coupler **310**, the RF rectifier **401** will carry a given rectified signal current. The current will be converted to a filtered voltage by capacitor **403**. Any change in the transistor power through directional coupler **310** will change the current through the detector load resistor **405**. The DC output voltage on line **407** is a function of the forward junction voltage of rectifier diode **401**. In an alternative arrangement for RF detection, a voltage rectifier circuit of conventional design can be used as the sensor. The reflecting RF detector and DC detectors and bias control circuit are not shown in FIG. 3 to simplify the illustration.

[0032] Although this illustration references a forward directional coupler, it will be appreciated that a reverse (or reflected) directional coupler, and DC voltage and current detectors also could be used. Also, while this illustration describes a power control scenario, other fault management functions, such as DC bias control, gain and phase adjustment and RF matching network adjustment could be used.

[0033] The DC detectors **201** and **202** in FIG. 2 can be of conventional design with the qualification that the sensed current or bias voltage data is transmitted as data signals to a microprocessor, or digital signal processor, including diagnostic and control circuitry on

chip **214** which receives the sensed information by the DC detector circuit via the above-mentioned data formatting and control circuit **211**, optical driver/detector **213**, and optical interface **210**. The microprocessor's diagnostic and control circuitry **215** at chip **214** compares the data to reference values and if necessary provides an error signal to active bias compensation circuits provided within DC detection and control circuits **201** and **202** on chip or wafer **206** which can reset or effect appropriate adjustments in the direct current (DC) or quiescent biasing point for RF power amplifier **208** or matching circuits.

[0034] Referring to FIG. 5, in one embodiment, the enclosure **205** and above-described integrated components on chips **206** and **214** housed therein together represent a power module **500**. The power module **500** includes the enclosure **205**, which in this illustration includes a metal cover **501**, such as aluminum, and may include gasketing **502** and extrusions, such as silver-silicone elastomer, to provide electromagnetic shielding. The cover **501** is attached to heat sink base **503**, which also may comprise aluminum, but may be fabricated from any high thermal conductivity metal. The enclosure can optionally include a forced air cooling device (not shown), such as a DC or AC fan, such as in a conventional manner to provide forced air over the fins **505** of the heat sink **503**. The package **207** can be a plastic and ceramic casing that is microstrip compatible or surface mountable, and includes an integral optical lens **219**. In one embodiment, the enclosure **205** and above-described integrated components housed therein together represent a power module **500**. As an alternate approach a non-metal cover, such as plastic, may be used.

[0035] Referring to FIG. 6 is a block diagram of a base station **600** that can incorporate the power module **500** of FIG. 5, and mobile units **602** and **603** are shown. The number of mobile units is not particularly limited to the number used in this illustration. As shown in this example, a public switch telephone network (PSTN) is connected to a mobile switching center (MSC) **605**, that also communicates with other mobile networks. The MSC **605**, in turn, connects to a central base station controller (CBSC) **607** that includes a data interworking unit and a path routing gateway. An output from the CBSC **607** is supplied to base station **600** that includes a transmitter and antenna and hardware and software for timing of the signal and for optionally spreading out the signal.

[0036] FIG. 7 illustrates a block diagram of equipment used at a base station **600** located at a gateway base site. A microcomputer **701** receives data via a buss **702** from a microcomputer interface **703** that in turn receives messages and data packets from a switch controller (not shown) connected to CSBC **607**. This same buss **702** also permits coupling

between the microcomputer **701** and base radio equipment **706** via buss **709**. This base radio equipment **706** includes a transmitter **500**, such as described above, having a power module. The base radio equipment **706** also preferably includes a receiver **707** for receiving wireless data, such as voice and data packet messages, and optionally location information, such as from mobile station via a satellite and may supply such data through an analog-to-digital (A/D) converter (not shown) to the microcomputer interface **703**. A memory **704** is coupled by a buss **705** to the microcomputer **701**. The base radio equipment **706** may also provide digital data directly to the microcomputer interface **703** via a buss **709**. Also coupled to the microcomputer **701** via buss **710** is path routing logic **711**, which in turn is coupled to a source or table of path descriptions and gateway locations. As shown, the path descriptions and gateway locations table **712** is also coupled to the CSBC **607**.

[0037] Location determining circuitry **713**, which receives location data from a satellite via satellite antenna **714** in one optional approach, is coupled by a buss **715** to the microcomputer **701**. Location register **716**, including mobile location, direction and time stamps is coupled via a buss **717** to the microcomputer **701** as shown. If desired, the location register could be located at another location such as at a switch or at a service control point (SCP). When a message or a data packet is received at the base station **600** for a particular mobile unit **602**, **603**, and so forth, the message is transmitted by radio transmitter to the designated mobile station.

[0038] One of the facets of a preferred embodiment is that the diagnostic fault management and control circuitry provided on external chip **214** (see FIG. 2) can, in turn, communicate with higher levels of the base station, such as microcomputer **701** via buss **709** and microcomputer interface **703**. In this manner, the power module is not merely deployed as a stand-alone assembly with preprogrammed diagnostic, fault management and control. In this embodiment, the microcomputer **701** can be used to update, reset, review, monitor, introduce commands related to channel traffic control, and so forth, relative to the diagnostic fault management and control circuitry and functionality provided on external chip **214** to enhance the benefits obtained by the system.

[0039] As will be appreciated, such an embodiment provides an advantageous integrated system for RF power device diagnostics and fault management, and, more particularly, such a system having an integrated circuit wafer or chip including an RF power device and fault detectors, and an optical interface for communications between the integrated circuit wafer or chip and diagnostic processing and control.

[0040] This approach eliminates the necessity of using a hard wire interconnect to convey error detection and correction information between different chips supporting the RF power device. The present embodiment provides an interface between a semiconductor chip with co-existent on-chip metal and optical signaling and a processing entity located off-chip without need for a physical connection, such as an optical fiber, to support propagation of the optical signaling.

[0041] Having detection circuitry co-located on-chip with the RF power device eliminates error resulting from off-chip detection, i.e. error that otherwise could occur due to parasitics associated with bringing a sample of the RF signal off-chip. This is done by an optical detector in the diagnostic processing circuitry, which is located within the same enclosure as the RF device, while being sufficiently separated to ensure no significant RF interference, receives the diagnostic information for subsequent interpretation and processing, and an optical driver in the processing circuitry that transmits fault management signals to the RF power device. Another advantage of this approach is reduced pin count on higher level packages for RF power devices (RF integrated circuits for example), since a large number of separate signals (which would normally require separate pinouts and possibly multiple ground reference pinouts) can be multiplexed onto a single optical link which does not require a hardwire pinout.

[0042] The systems for integrated RF power device diagnostics, fault management and control of such embodiments can be used in virtually any application that uses RF power transistors. Examples include, but are not limited to, base station transceivers and base station transmitters in particular, mobile and portable transmitters in telecommunication applications, RF power amplifiers, and instrumentation amplifiers, and so forth.

[0043] For example, the RF Power device diagnostics and fault management system **200** of the present embodiment can be used for both non-constant envelope applications like CDMA and TDMA power amplifiers and constant envelope applications like GSM and analog power amplifiers. The system **200** also is applicable to other linear applications such as multicarrier and orthogonal frequency division multiplexing (OFDM). The system **200** is suitable for multi-mode and multi-band cellular telephone applications. The system **200** also can be used in mobile telephone applications, and in other non-cellular applications such as public or private 2-way land mobile radio systems or other non-two-way applications such as instrumentation amplifiers.

[0044] Referring to FIG. 8, an aspect of a preferred embodiment that is relevant to implementation is directed to the capability of fabricating an integrated RF power device assembly including the RF power device or devices, the DC and RF detector and control circuits, the thermal detector circuits, the signal processing circuitry, and the optoelectronic devices and controls used to support the optical interface, in a common unitary monolithic semiconductor structure. This implementation preferably is performed in monocrystalline compound semiconductor material and monocrystalline silicon material that are integrally and compliantly formed, at different lateral locations, upon a monocrystalline substrate unitary monolithic semiconductor structure via an intervening stress-relieving substructure. Methods and materials for implementing integrated circuits and devices in both high quality monocrystalline compound semiconductor structures, namely, Group III-V compound semiconductor structures like GaAs and so forth, and monocrystalline Group IV structures, namely, silicon and/or germanium structures, upon the same handle wafer, is made possible by fabrication methods generally described in commonly assigned U.S. Patent Nos. 6,472,276 B1 and 6,392,257 B1, which describe the provision and use of a unique strain-relieving substructure provided in such composite semiconductor structures, which descriptions are incorporated herein by reference. The above-incorporated '276 and '257 patents describe a method and materials that are applicable here for monolithic integration of Si based logic circuitry with group III-V optoelectronic devices using the same handle wafer, which can be used for high temperature and high power RF applications and optoelectronics. Such methods and structures are available to those skilled in the art to facilitate the making of integrated RF power assemblies on a single chip as described herein.

[0045] As shown in FIG. 8, the RF power device and detection circuitries provided on chip **206** are comprised of a plurality of elements, previously identified in FIG. 2, arrayed upon a common silicon substrate **800**. The elements are preferably monolithically fabricated as a unitary structure by fabrication methods such as those generally described in commonly assigned U.S. Patent Nos. 6,472,276 B1 and 6,392,257 B1. Generally speaking, these various elements are substantially intimately situated and connected upon the same substrate **800** via an accommodating buffer layer and strain-relieving interface layer.

[0046] For instance, the RF power amplifier can be implemented by fabrication of LDMOS in CMOS. The data formatting and control circuitry **211** and detection and control circuitry **202** and **204** can be implemented in either CMOS or a compound semiconductor material formed upon the common silicon substrate, but typically will be done at least partly

using complimentary metal oxide semiconductor (CMOS) methodology. The optical driver/detector element **213** can comprise any optical frequency-based carrier mechanism including, for example, infrared, visible light, ultraviolet light, and so forth. For purposes of this illustrative description, the optical driver/detector element **213** comprises infrared (IR) output elements and IR input detector elements implemented in layers of compound semiconductor material (such as, for example, monocrystalline Group III-V compound semiconductor material) that has been grown over the common silicon substrate **800** via the accommodating buffer structure. In general, the choice between forming the circuits or devices in CMOS or a compound semiconductor material will include due consideration of the cost and performance requirements for a given application. Specific approaches by which to effect such structures are known in the art and are specified, for example, in publications such as those noted above. Therefore, for the sake of brevity and the preservation of clarity and focus, further elaboration regarding such details will not be set forth here.

[0047] Such processes permit the RF amplifier, silicon-based digital logic processing circuitry, the optical detector and output sensor, and the detection circuitry for the RF amplifier to be integrated onto a single chip and die. This makes it possible to provide a more reliable part while reducing fabrication costs, and reducing the space required to package the part otherwise entailed by the prior use of multiple dies and hardwire connections therebetween.

[0048] In the foregoing specification, various embodiments have been described. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of present invention.

[0049] Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential features or elements of any or all the claims. As used herein, the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only

those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.